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Ignoring Ecosystem-Service Cascades Undermines Policy for Multifunctional Agricultural Landscapes

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Over and above food, agricultural landscapes provide citizens with crucial public-good ecosystem services, such as biodiversity conservation, cultural values, recreational opportunities, and food security. Because continuing agricultural intensification undermines the ability of landscapes to provide public goods, policies have been implemented to preserve landscape multifunctionality, but with limited success. We suggest that one reason for this lack of success is that the cascading nature of ecosystem services has not been sufficiently addressed. While different definitions of multifunctionality emphasize different parts of the service cascades, we argue that efficient policies targeting multifunctionality simultaneously need to consider ecosystem services along the entire cascade, i.e., both intermediate and final ones. By understanding how multiple final ecosystem services are promoted by single measures with effects on multiple intermediate ecosystem services or by single intermediate ecosystem services with effects on multiple final ecosystem services, measures can be identified that simultaneously benefit private and public goods, allowing the latter to hitchhike on management for the former. Even if such synergistic solutions are less efficient in terms of promoting yields compared to non-synergistic solutions, policies such as payment for ecosystem services to promote them may be cost-efficient since the private benefit reduces the need for public payment. Furthermore, by focusing on the ecosystem service cascade, social-ecological scale-mismatches along the cascade hampering the implementation of synergistic solutions can be identified and targeted by policy. We exemplify our reasoning with the potential benefit to biodiversity conservation from yield-enhancing ecosystem services.

Keywords: multifunctionality, ecosystem services, ecosystem-service cascade, multifunctional agricultural landscapes, agri-environmental measures

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AGRICULTURAL INTENSIFICATION THREATENS LANDSCAPE MULTIFUNCTIONALITY

Agricultural landscapes produce a multitude of goods and services of value to humans, including both private goods such as food, feed, and biofuels, and public goods such as biodiversity conservation and water and climate regulation. Hence, agricultural landscapes are intrinsically multifunctional (Van Huylenbroeck et al., 2007). Intensifying agriculture through increased use of external inputs and landscape simplification has resulted in higher yields at the expense of the environment, putting a range of public goods and services at risk (Foley et al., 2005; Stoate et al., 2009). It is well-appreciated that ecosystem services in farmland that are pure public goods (non-rival and non-excludable), such as climate regulation and biodiversity conservation (as a final ecosystem service, Mace et al., 2012), may be undersupplied because land-owners will carry the cost supporting them while not being able to internalize the benefits which will be shared with others ("Tragedy of Ecosystem Services," Lant et al., 2008). However, it is less appreciated that several ecosystem services underpinning yield—a private good—may also be undersupplied because they depend on mobile organisms and therefore have some properties of public goods (e.g., pollination, Cong et al., 2014), or because benefits occur in a distant future that is not sufficiently valued given current discount rates (e.g., soil carbon sequestration to benefit nutrient retention, Baveye et al., 2016). Thus, agricultural intensification also threatens sustainable crop production, by eroding essential supporting and regulating ecosystem services (Matson et al., 1997; Power, 2010).

The understanding of agricultural landscapes as an ecosystem providing functions that underpin the generation of a variety of ecosystem services, has created a need to restore or maintain agro-ecosystem functioning (Pretty et al., 2001; Van Huylenbroeck et al., 2007). Currently society tries to achieve this by environmental regulations and by offering payments to farmers for implementing measures to reduce environmental impacts and enhance biodiversity. For example, in Europe farmers must perform certain greening measures to obtain direct payments and a number of agri-environment schemes compensate for costly measures that reduce environmental harm (Kleijn and Sutherland, 2003; EU, 2013). However, these policy instruments are not without problems. Cost-increasing regulations may affect agriculture's competitiveness on global markets and agri-environmental schemes may be inefficient because farmers select actions that are least costly to implement rather than those that are most efficient. In general, the European agri-environmental policies have been deemed both inadequate and insufficient (Pe'er et al., 2014; Leventon et al., 2017).

While there is an urgent need to find effective management and policy instruments to restore farmland multifunctionality, the term multifunctionality is used with different definitions in the scientific literature. In this Perspective article, we show how these different definitions can be linked to the understanding of ecosystem services as cascades (sensu Haines-Young and Potschin, 2010), and that simultaneously focusing on the entire cascade can help to identify cost-efficient solutions to benefit both private and public goods in multifunctional agricultural landscapes.

DEFINING MULTIFUNCTIONALITY IN THE ECOSYSTEM SERVICE CASCADE

The term multifunctionality may refer to the ability of landscapes to provide multiple ecosystem services (Mastrangelo et al., 2014). Thus, multifunctional landscapes produce both private ecosystem services and ecosystem services that are public goods. The closely related term multifunctionality of agriculture more narrowly focuses on the contribution of agricultural activities as such, to the joint production of commodity and non-commodity outputs (OECD, 2001; Van Huylenbroeck et al., 2007). There is a large body of research focusing on how to support multifunctionality, e.g., by finding the optimal trade-offs and synergies among different final ecosystem services (see e.g., Nelson et al., 2009). The term multifunctionality is also used, however, with a slightly different meaning, to describe the ability of ecosystems to provide the multiple ecosystem functions that underpin ecosystem services (Byrnes et al., 2014; Soliveres et al., 2016). Because of this conceptual pluralism, there is a need to clarify the relationship between the multifunctionality concepts. This can be done by linking them to the concept of the ecosystem service cascade (sensu Haines-Young and Potschin, 2010). In the cascade a distinction is made between intermediate and final ecosystem services (sensu Fisher et al., 2009), which are related to each other in a causal chain (Haines-Young and Potschin, 2010; Spangenberg et al., 2014). A cascade perspective on multifunctionality simultaneously focuses on the underlying drivers and processes that provide ecosystem functions (i.e., intermediate ecosystem services; Pasari et al., 2013), the joint supply of ecosystem services, and the capacity of a landscape or management practices to simultaneously support multiple benefits to society (i.e., final ecosystem services; Mastrangelo et al., 2014). Thus, ecosystem multifunctionality also considers the supply of intermediate ecosystem services, whereas landscape multifunctionality focuses on the supply of multiple final services.

It can be argued that multifunctional agricultural landscapes (sensu Mastrangelo et al., 2014) require ecosystem multifunctionality (sensu Byrnes et al., 2014). However, we argue that the relationship is more complex, because single functions can underpin multiple services and single services may require multiple functions (**Figure 1**). For example, a single agri-environmental measure such as fallows may benefit the intermediate function carbon sequestration, and thereby result in both climate regulation and enhanced future yields. Another measure, such as buffer strips, may reduce nutrient runoff and at the same time benefit pollinators by providing undisturbed habitat, benefitting both environmental quality and current yields (Brady et al., 2015). Although there are emerging frameworks linking functions and services in agricultural landscapes (van Zanten et al., 2014), these do not explicitly consider such complex relationships.

EXPLORING SYNERGIES ALONG THE ECOSYSTEM SERVICE CASCADE TO BENEFIT MULTIFUNCTIONALITY

Various policy measures are required to benefit the provision of ecosystem services that are public goods, whereas management benefitting private goods is expected to be implemented when gains to landowners are sufficiently large compared to the cost of ecosystem service management. Thus, if management

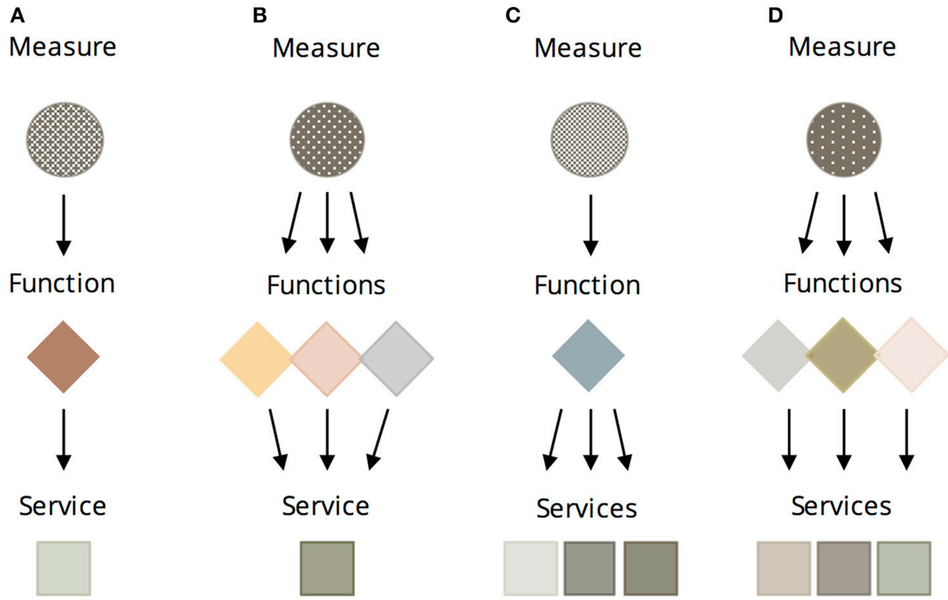

FIGURE 1 | A conceptual representation of a cascade based understanding of how agri-environmental measures can enhance one or several ecosystem services. These services come as a result of benefitting organisms performing one **(A,C)** or several **(B,D)** relevant ecosystem functions. The figure illustrates that multifunctional landscapes can be achieved either through benefitting several functions **(B)** or through a single function with benefits multiple final services **(D)**.

of intermediate ecosystem services is a cost-efficient means to promote yields, we can expect them to be promoted given that farmers have sufficient information about their contribution to yields. For example, given sufficient evidence of the benefits, farmers would gain by promoting ecosystem services such as crop pollination by wild pollinators (Uyttenbroeck et al., 2016). However, the management actions undertaken to benefit the provision of intermediate ecosystem services benefitting crops may incidentally benefit public goods (i.e., joint production). In particular, some management actions may have such multiple benefits, because the intermediate ecosystem services (or ecosystem functions) that they benefit simultaneously affect both private and public goods positively. A prime example is carbon sequestration to benefit both climate regulation and crop yields. Thus, we can expect uptake of measures that benefit public goods when they are in synergy with private goods, but only if the yield benefit is greater than the cost of implementing the measure.

To be able to take advantage of synergy effects between private and public goods we need to understand the multifunctional consequences of measures in a cascade perspective. By this we mean, whether they benefit multiple intermediate services and/or if they enhance an intermediate service that benefits multiple final services, that in either case results in increased production of both private and public goods (see also **Figure 1**). While it is a challenge to evaluate if agri-environment measures have the intended effects on single environmental benefits such as biodiversity (e.g., Dicks et al., 2014), it will be even more challenging to evaluate how they simultaneously contribute to multiple ecosystem services.

While there are many possibilities to explore multifunctional consequences of managing intermediate ecosystem services, particularly letting public goods hitchhike on management for private goods, there are also several challenges with this approach. First, some actions to benefit private goods by increasing yields are detrimental to public goods, because they degrade the environment (e.g., mineral fertilizer and pesticide application). Thus, it may be important to consider internalizing the cost of environmental externalities or use other policies to reduce the use of such management (as well as internalizing positive environmental externalities, if any). Second, the management providing multifunctional benefits may not be the most profitable for the farmer. Fallows may, for example, have more multifunctional consequences by benefitting both biodiversity and soil quality, compared to ley in the rotation which may mostly target soil quality, but the latter may be more economically beneficial for the farmer. Thus, payments for ecosystem services by society may be needed to steer management to those actions with multifunctional consequences, but the necessary payment from society (PES) may be lower than when considering the provisioning of public goods alone, because the synergies with private goods reduce the net cost to landowners (**Figure 2**).

Third, since some intermediate ecosystem services need to be managed at scales larger than farms, even if the final services they benefit are private, optimizing these services for their private benefit is likely to require some form of collaboration among neighbors (Goldman et al., 2007). For example, while pollination benefits yields, the mobility of pollinators may require that they are managed at scales larger than an individual farm. However, such collaboration could be hard to achieve in practice because of the problem with free riding, i.e., when a farmer benefits from the actions of a neighbor (Cong et al., 2014). Thus, there might

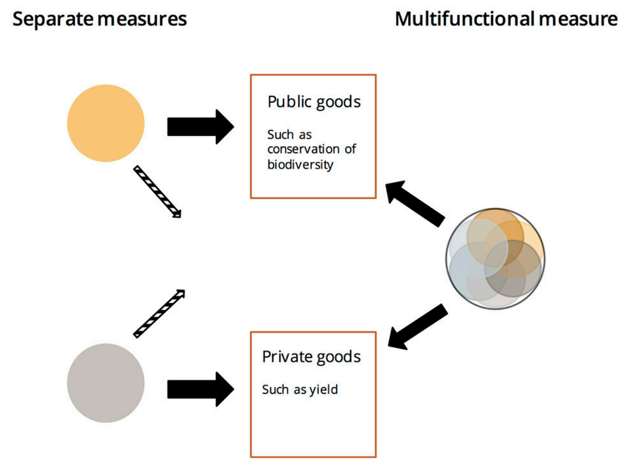

FIGURE 2 | A conceptual view of measures benefitting public and private goods separately, versus a multifunctional intervention, benefitting both public and private goods. The size of the arrows indicates the effect the measure has on the service, a specialized intervention targeting only one type of service might have a higher effect on that service than a multifunctional measure, targeting both public and private goods jointly. The striped arrows represent small fortuitous benefits on other types of ecosystem services. A measure with the objective to benefit yield through increased pollination may for example benefit also a rare insect species.

be a need for incentivizing farmer collaboration through policy (Goldman et al., 2007; Franks and Emery, 2013).

Finally, it is an open question to what extent synergistic solutions are more cost efficient than focusing on management that separately targets private and public goods. This has recently been the target of the debate on land-sparing vs. land-sharing (Fisher et al., 2014). However, only by knowing the full consequences of management for multiple ecosystem services, can the merits of synergistic vs. separate management solutions, be determined. This can be depicted in ecosystem service production possibility frontiers, that describe the possible outcomes for the production of multiple ecosystem services (e.g., Smith et al., 2012). For example, it remains to be determined if climate mitigation is best supported by society by targeting management that also benefits soil quality, or if payments to plant forest are more cost efficient for mitigation, leaving it to farmers to make decisions about maintaining soil quality based on their concern for the future.

BIODIVERSITY CONSERVATION VS. MANAGEMENT OF YIELD-ENHANCING ECOSYSTEM SERVICES

Even though rare species of bees contribute to crop pollination (see e.g., Garibaldi et al., 2013), it is the common species, those that persist in modern agricultural landscapes, that are the most important service providers (Kleijn et al., 2015; Senapathi et al., 2015). However, some rare and threatened species are dependent on the agricultural landscape, for example because they harbor species associated with nature types that have become rare (see e.g., Sutcliffe et al., 2015). As such, a trade-off between biodiversity conservation and crop pollination may exist and measures taken to promote pollinators in agricultural landscapes may not benefit rare specialist species of for example bees. In England, flower strips created with the intention of benefiting pollinators have been shown to benefit quite common species of bees while rare species, with more specific demands for flower resources, used other flowers in the landscape (Wood et al., 2017). The question is whether there are synergistic solutions that promote both biodiversity conservation and ecosystem services underpinning yield in agricultural landscapes (Ekroos et al., 2014). Is it sufficient to add other plant species, better suited for rare solitary bees, to the seed mixes for flower strips as suggested by Wood et al. (2017) or is it better to integrate permanent semi-natural habitats such as meadows in the agricultural landscape (see e.g., Ekroos et al., 2013; Nayak et al., 2015)? How much does crop pollination benefit by doing so, compared to similar investment in flower strips? To answer these questions requires cost-effectiveness analysis with e.g., multiple environmental targets.

The sharing vs. sparing framework has been used to compare the value of preserving natural habitats to the integration of conservation in anthropogenic landscapes (Green et al., 2005; Fischer et al., 2014). The consequences of the two strategies on intermediate ecosystem services have been absent in these discussions (e.g., benefits of sharing for pollinators), making the overall comparison of the merits of the strategies difficult. However, the framework can be modified to discuss prioritizing of actions with different values for conservation of rare species and benefits to ecosystem service providers (Ekroos et al., 2014). An essential discussion will be to what extent it may benefit society to use payments to tailor landscapes to benefit both ecosystem services providers and rare species, compared to focusing on conserving species by land-sparing. The payments needed to implement certain actions, such as preservation of semi-natural habitats embedded in agricultural landscapes, may then depend on if these also entail benefits to farmers in the form of ecosystem services underpinning yield. Since ecosystem services such as crop pollination depend on mobile organisms such as bees that may move between farms, a cost-efficient approach may require collaborative solutions as suggested above (Goldman et al., 2007). To do this we require good knowledge of the relationship between potential measures and outcomes on multiple indicators, but this knowledge is still often lacking.

CONCLUSIONS

To conclude, we suggest that ecosystem services in agricultural landscapes must be understood as the cascade they are a part of, where intermediate and final services rely on one or several underlying ecosystem functions. Although the ultimate goal is to have landscapes that provide optimal levels of both private and public ecosystem services (multifunctionality), we mean that by an improved understanding of the underlying interactions in the ecosystem service cascade, we can better exploit synergies and avoid trade-offs. Further, we suggest that the "tragedy of ecosystem services" to some extent can be overcome if policy considers both the private and public goods that are generated through agri-environmental measures and explicitly state this as a goal. Understanding and utilizing the fact that there are sometimes synergies between ecosystem services at small spatial scales that may benefit yields and ecosystem services at large spatial scales that are public goods is crucial for efficient policy design (e.g., carbon sequestration for nutrient retention and climate regulation). By exploiting these synergies—letting public goods hitchhike on the private goods—efficacy and societal cost-efficiency could be increased for agri-environmental schemes.

AUTHOR CONTRIBUTIONS

HS originally conceived the idea. LN further developed the idea and wrote the manuscript with significant input from HS. All other authors contributed to the final manuscript.

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